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The Patent Office
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NP10 8QQ

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REC'D 20 JUN 2000

WIPO PCT

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Signed

Dated 07 JUN 2000

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Patents Form 1/77

Patents Act 1977
(Rule 16)

The Patent Office

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26 APR 1999
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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

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1. Your reference — P006777GB JMP.KT

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2. Patent application number *(The Patent Office will fill in this part)* — 26 APR 1999 — **9909572.1**

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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

SIMAGE OY
Tekniikantie 12
02150 Espoo
Finland

Patents ADP number *(if you know it)* — 857254001

If the applicant is a corporate body, give the country/state of its incorporation — Finland

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4. Title of the invention — A HARDWARE TRIGGER FOR THE SIMAGE INTRAORAL X-RAY SENSOR

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5. Name of your agent *(if you have one)* — D YOUNG & CO

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

21 New Fetter Lane
London EC4A 1DA

Patents ADP number *(if you know it)*

---

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

---

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

---

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	~~18~~ 8
Claim*(s)*	
Abstract	
Drawing*(s)*	10

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature D Young & Co Date

D Young & Co 26 April 1999

12. Name and daytime telephone number of person to contact in the United Kingdom

Dr Julian Potter - 0171 353 4343

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

A Hardware Trigger for the Simage Intraoral X-ray Sensor

Table of contents:

Overview

Taking an intraoral exposure involves two triggers. The first comes from the user pressing for instance a button for the x-ray source (*X-ray Trigger*) while the second should come subsequently (ideally shortly before the actual exposure) to start the accumulation of a single image on the image detector and do subsequent readout (*Exposure Trigger*).
Important corner points are:

- Accurate timing of the *Exposure Trigger* is needed to minimize dark current accumulation on the detector.
- X-ray source may have a variable time delay from the *X-ray Trigger* to the actual X-ray emission and may not have an *Exposure Trigger* output. (Retrofitting!)

A self-triggering sensor system is, therefore, desirable to allow maximum flexibility with minimum user interaction without loosing performance.

Self-triggering CCD

An obvious way is to read-out the detector continuously and to use the pixel values to determine the *Exposure Trigger*. This means on a CCD pixel values are continuously clocking towards the readout edge. Any image information before the trigger stops the clocking is lost and smeared sideways over the imaging area.

Self-triggering Simage Intraoral X-ray Sensor

The direct X-ray to electron conversation of the Simage Intraoral X-ray Sensor suggest the usage of the bias current applied to the detector representing the average signal on the entire detector as a means for determining the *Exposure Trigger*. This together with the direct (not smearing) pixel readout of the detector it should allow to develop a very robust system generating an *Exposure Trigger*.
As start point for this investigation is edge detection as the simplest form to generate a trigger from the bias current measurement.

! Please keep in mind any more sophisticated processing (integrating,...) can be done as well.

Edge-detection on the Bias Current

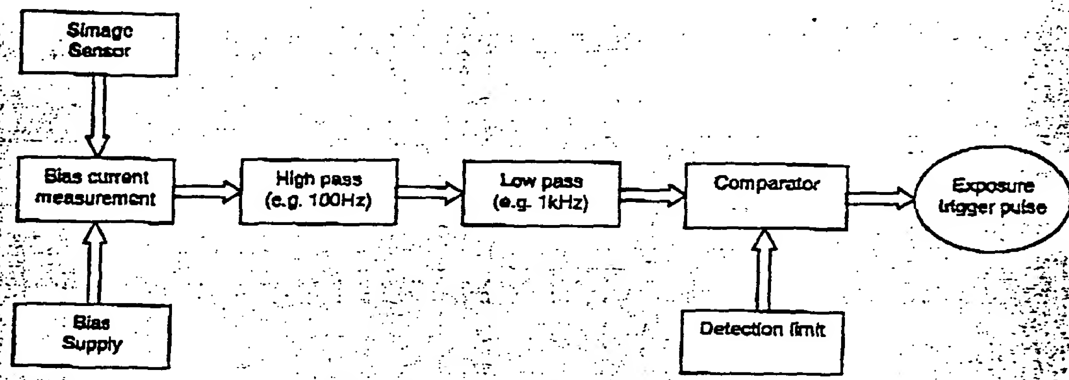

Figure 1: Implementation of an Edge Detection Trigger

Figure 1 shows the block diagram of an edge detection trigger system. The main components are the two filters acting together as a band pass with the frequency band $f_{High\ pass}/f_{Low\ pass}$.

$$f_{High\ pass} = 2/t_{X-ray\ pulse\ duration} \qquad f_{Low\ pass} = 2/t_{X-ray\ pulse\ rise/fall\ time}$$

In fact, the two filters allow direct control of disturbance rejection of the trigger and it may become adversely effective to narrow the frequency band $f_{High\ pass} - f_{Low\ pass}$ and incorporate higher order filters with steep characteristics.

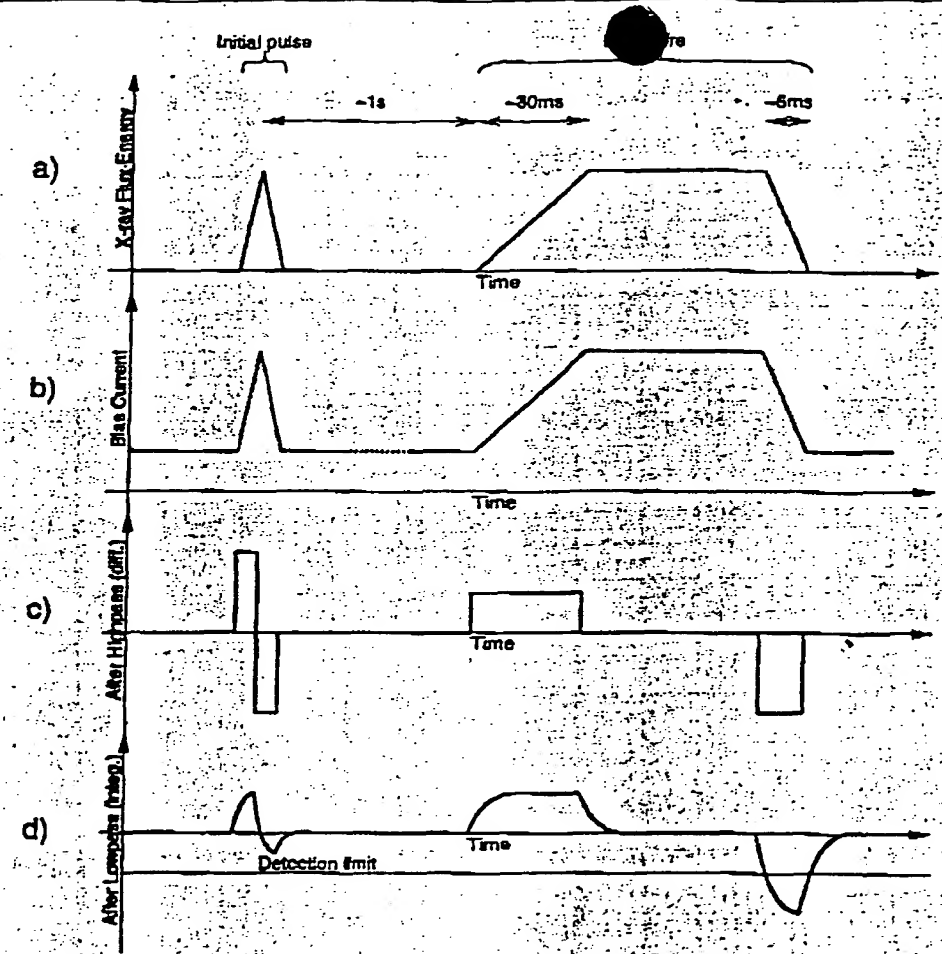

Figure 2: Edge detection on a typical X-ray exposure via bias current measurement

Figure 2 a) shows a typical X-ray intensity coming from the X-ray source used for dental imaging. Typical for certain x-ray sources is a pulse of X-rays sent out prior to the actual exposure. The actual exposure has a relative flat rising and a steeper falling transient of X-ray intensity.

The initial pulse may be timely related to the *X-ray trigger* and the start of preheating the X-ray tubes filament. This may create a pulse of X-rays if the high voltage power supply is not well controlled.

The slow rise time of the exposure may be caused by slow build up of the high voltage in the power supply or correspond to X-ray tube heating.

Generally speaking, the two causes for the slow rise time do not apply to the falling edge at the end of the exposure. Therefore, it should be better detectable than the rising edges of the exposure.

Figure 2 b) shows the bias current as a direct measure of the X-ray intensity offset by the sensor dark current.

Figure 2 c) shows the signal after high pass filtering (~derivative).

Figure 2 b) shows the signal after additional low pass filtering (~integral).

⇒ The feasibility of the falling edge is now rather obvious.

Readout Sequence of the Sensor

General idea of the readout is to have a continuously working sensor with pixel values written into a physical ring buffer.

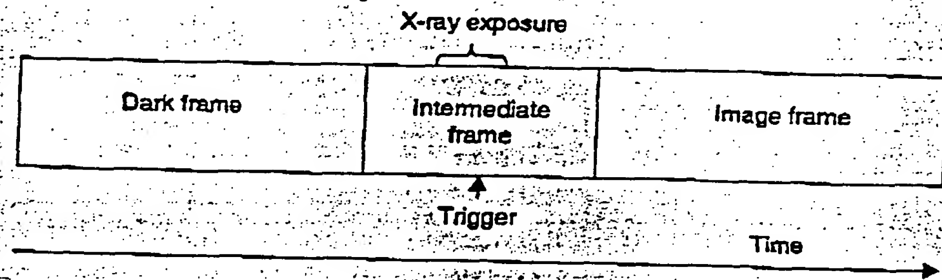

Figure 3: Readout sequence

In the event of the trigger three frames are defined as shown in Figure 3, whereby, the function of the dark and the image frame are rather obvious.
The intermediate frame is defined from knowledge of the trigger and knowledge of the duration of the X-ray exposure with a safe margin on both sides. Since this frame includes image data it has to be added up to the image frame pixel by pixel and preferably after calibration.

The usage of continuous readout (= intermediate frame) has pos. and neg. effects:

1. dark frame can be taken before image
2. the intermediate frame needs additional transfer time
3. requirements for the trigger are relaxed

Figure 4 shows an implementation of the ring buffer. Write and read access is done via pointers. Additional logic has to ensure a trigger can only occur after at least one dark frame is in the buffer as well as once the reading is started no data can be overwritten before reading.

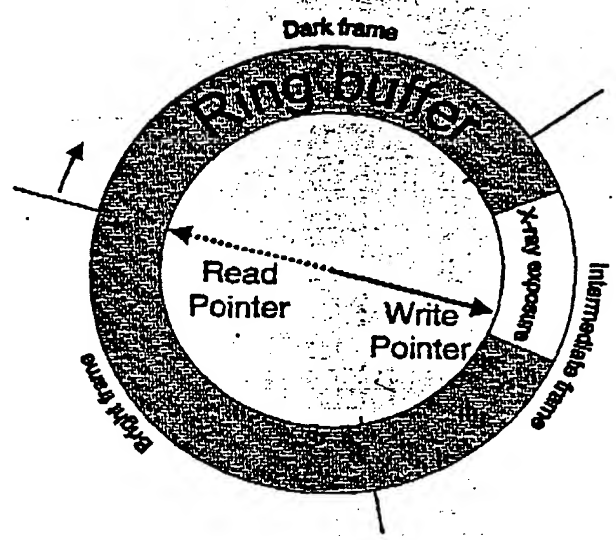

Figure 4 Ring buffer at Trigger time

First Prot[illegible]e of the Trigger

A first prototype of the trigger was implemented using a cheap quad op-amp since frequencies we are low and offset problems can be avoided using AC coupling.

Bias Current Measurem nt

The HV supply and the computer in the system are connected to the ground of the electrical system as well as the ground wire of the oscilloscope. Therefore, detecting the bias current measurement is done from a resistor at the high voltage side.
Measurement from the ground wire is possible in a floating configuration and offers a number of advantages as for example DC coupling and easy usage of a compensation measurement.

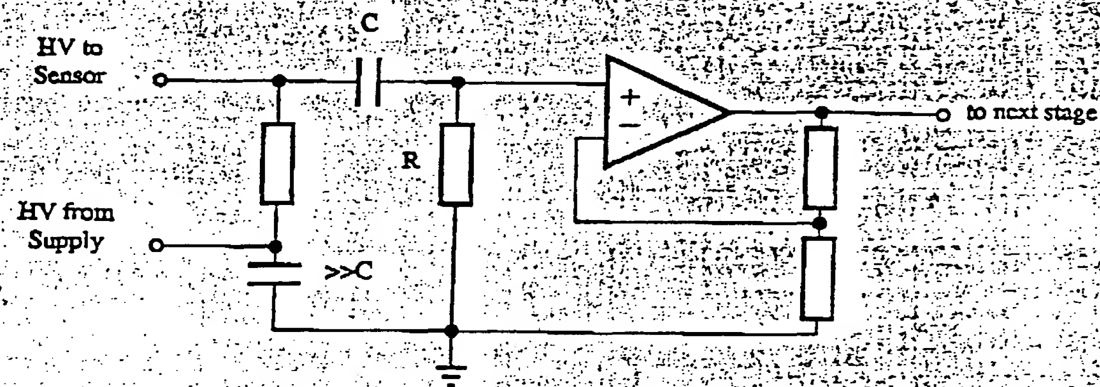

Figure 5: Bias current measurement

The RC cutoff frequency is chosen low compared to the subsequent high pass filter. The current sensing resistor is chosen providing a good detectable voltage drop tolerable by the sensor operation and being sufficiently smaller than R.

High and Low Pass

High and low pass are implemented as second order filters with critical damped characteristics. A simple change of the op amp gain allows more advanced characteristics (Critical = 1.0, Bessel = 1.268, 3dB Tschebyscheff = 2.234, ...).

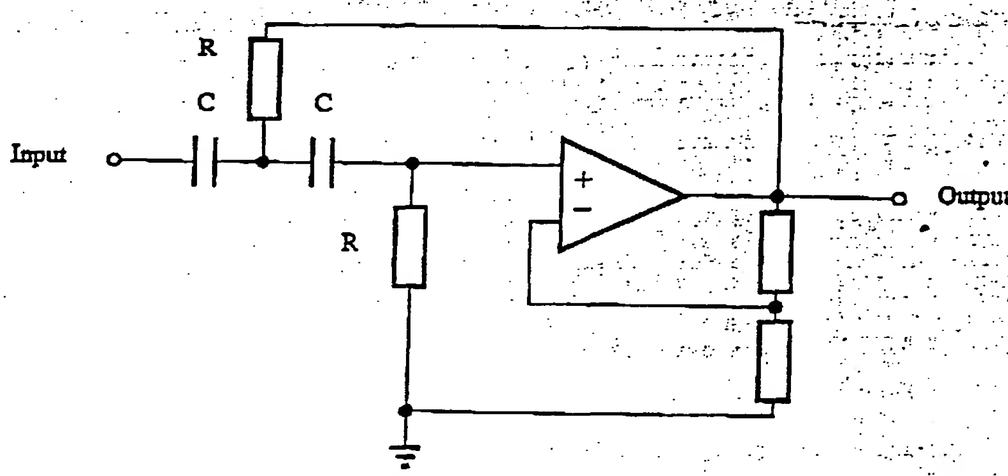

Figure 6: 2nd order high pass filter (for low pass interchange R and C)

Comparator

The comparator was given one-sided Smith-trigger behavior to provide some simple hold circuit and LED visualization. The input is AC coupled to reject eventual offset voltage of the preceding output.

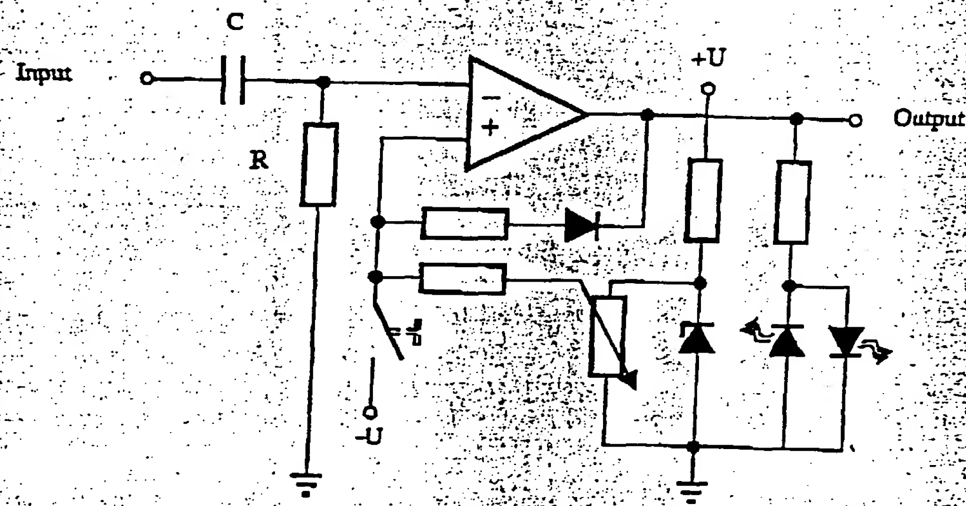

Figure 7: Comparator incl. Hold/Reset and Visualization

Results from the First Prototype

1. First results were obtained using a Planmeca dental X-ray source with the recommended 2 mm Al filtration and 30 cm focal spot to sensor distance.
2. The X-ray source is set to 8mA current, 63kV voltage and 10 ms duration.
3. Measurements were made with 200/2000 Hz and 100/1000Hz high pass/ low pass settings. For each filter combination the comparator was kept constant at maximum sensitivity (no unwanted triggering).
4. The sensor receives the clock signal. The sensor and the electronics are unshielded optically and electrically.
5. Tests were done without object, with a dental phantom, with 4 mm and with 12 mm Aluminum.

! All of the appended traces are inverted with respect to Figure 1 d).

! The trigger corresponds center of the plot.

Sensor in Standby (Plot 1-8)

No readout/reset was done on the sensor.

1. As the plots 1-8 show the X-ray exposure was safely detected.
2. The amplitude of the pikes is higher in the 100/1000Hz configuration compared to the 200/2000 Hz. The result is expected from the function of a high pass.
3. The traces without object show clearly the rising and the falling flank of the bias current.
4. With increasing object absorption only the pike corresponding to falling edge of the bias current stays above the noise floor.

- Without d t triggering occurs before the fall edge. This is because of sensitive adjustment of the comparator which now is registering an oversho from the rising edge as well as ripple of the X-ray intensity. With an adequately selected readout sequence should not impose a problem.

S nsor in Operati n (Plot 9,10)

Continuous readout/reset was done on the sensor.

1. Due to the relative simple filtering the reset frequency of the sensor (~30kHz) becomes visible forcing a higher comparator voltage thus reducing the sensitivity.
2. In the 200/2000Hz configuration the x-ray exposure could not be detected with 12 mm Al but very safely with 4 mm Al.
3. In the 100/1000 Hz configuration the x-ray exposure could still be detected with 12 mm Al.

Conclusions

Considering the introduced system as a very first try the results appeal very promising thanks particularly to the fact that exact detection of the start of exposure is not required.
From an improved implementation further noise decrease and, therefore, increased disturbance rejection can be expected, including minimized crosstalk from sensor operation.
There is a need to investigate different X-ray source since it is suggested different sources may have smaller rise and fall times the one in test. Also an initial pulse of X-rays was not observed with the used source.

1/10

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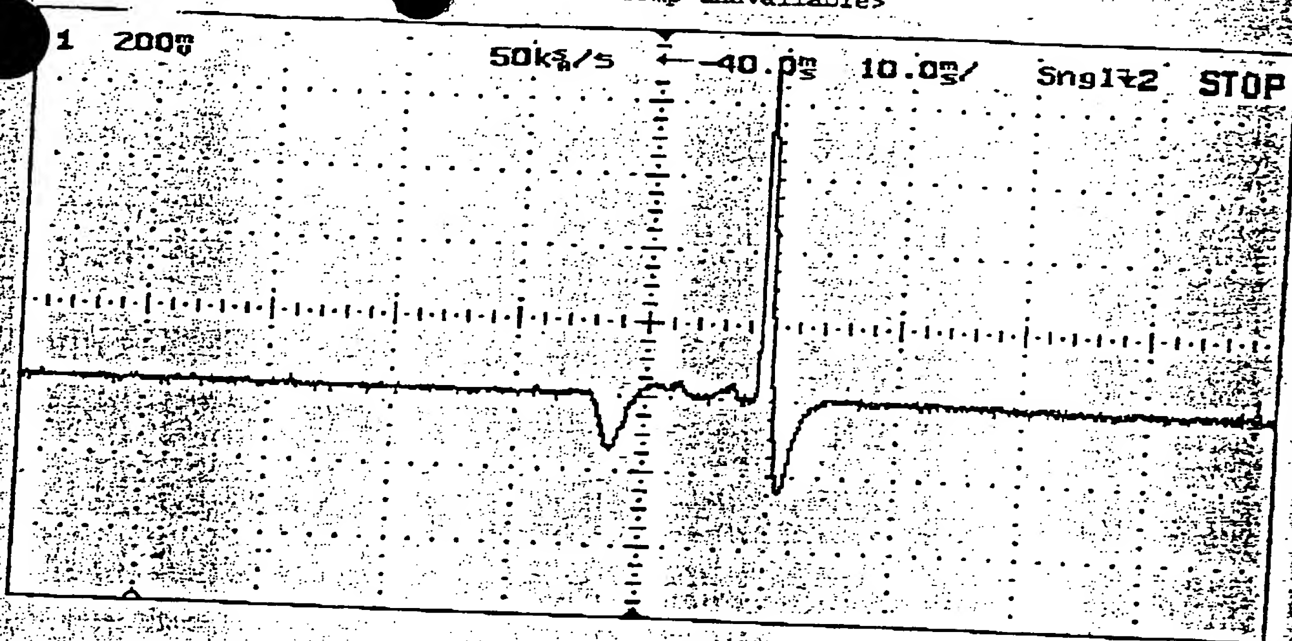

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Chan 1	On	200.0mV	-200.0mV	DC	Off	Off	10:1A	1M
Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

Trigger Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

nothing 200/2000 Hz

(same trigger than 12 mm Al ?)
for samp

Plot 1

21/04 '99 KE 10:12 FAX +358 9 43543700 SIMAGE OY

2/10

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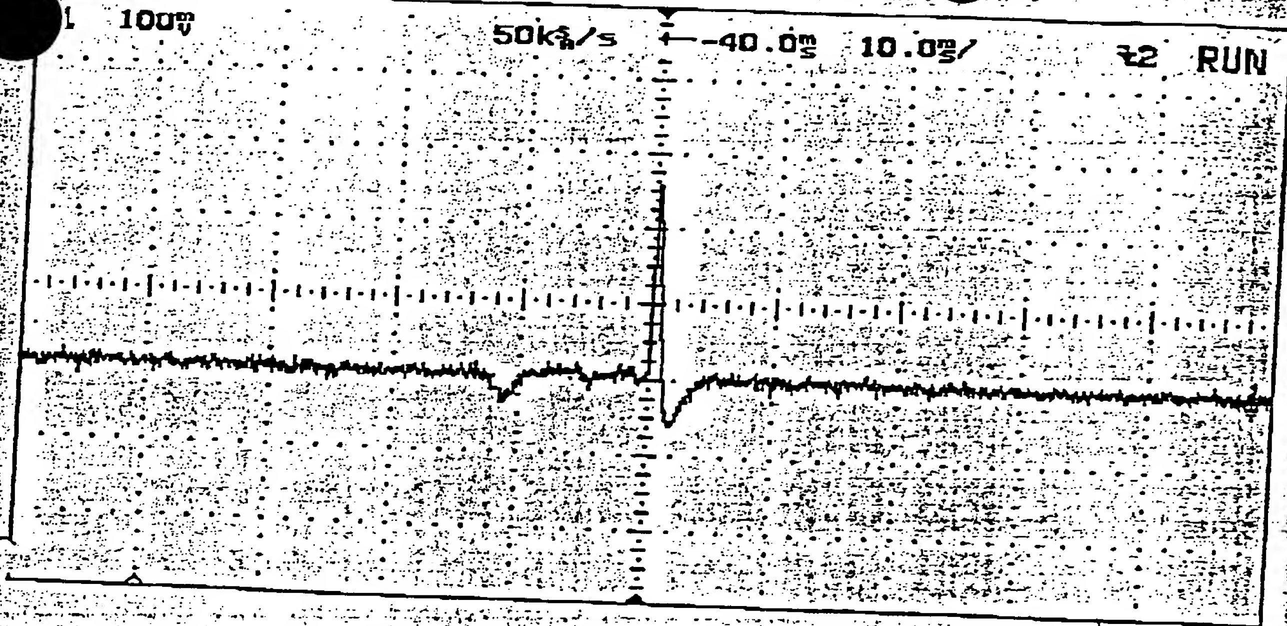

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Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

	Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Trigger	Normal	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

200 / 1000 Hz

Phantom

Plot 2

3/10

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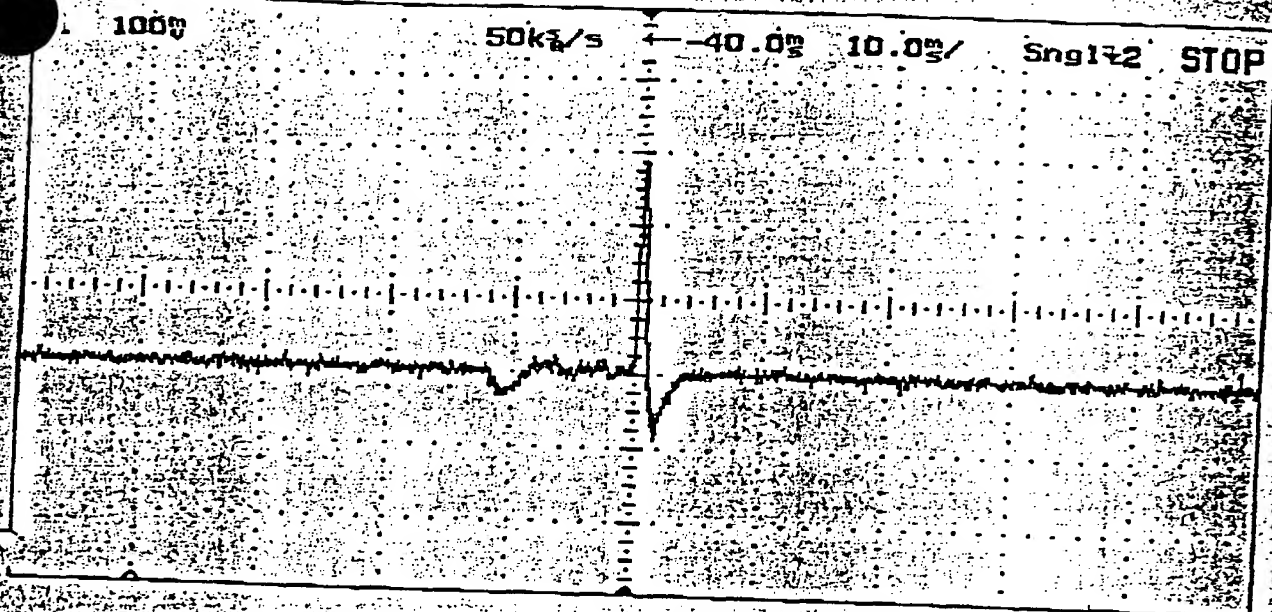

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Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

Trigger Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

200/2000 Hz

4mm AL

Plot 3

4/10

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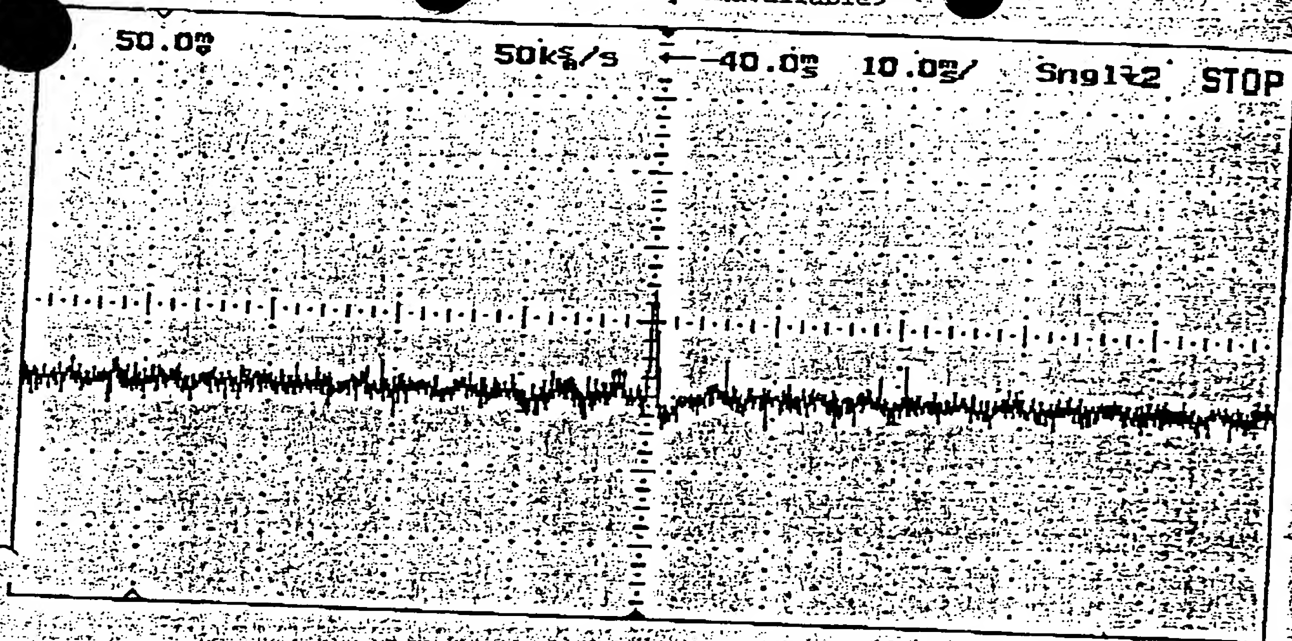

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Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

Trigger Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

12 mm AL 200/2000 Hz

Plot 4

5/10

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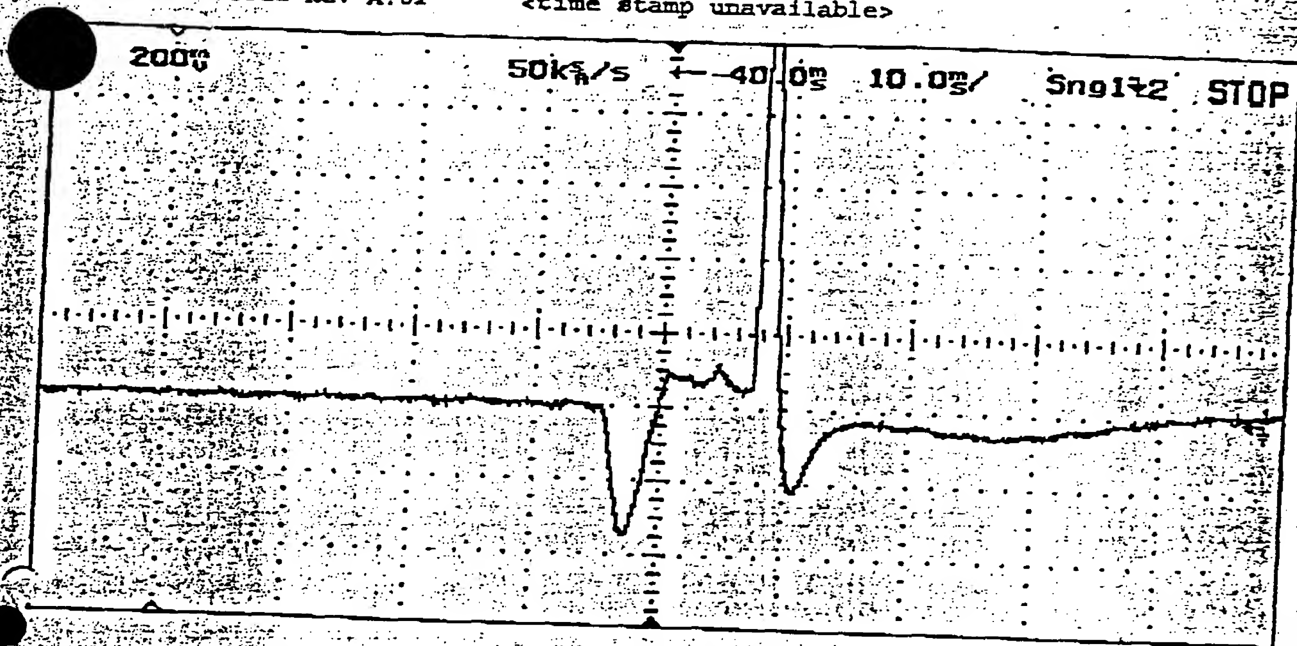

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Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

Trigger Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

100 / 1000 Hz
walking

Plot 5

6/10

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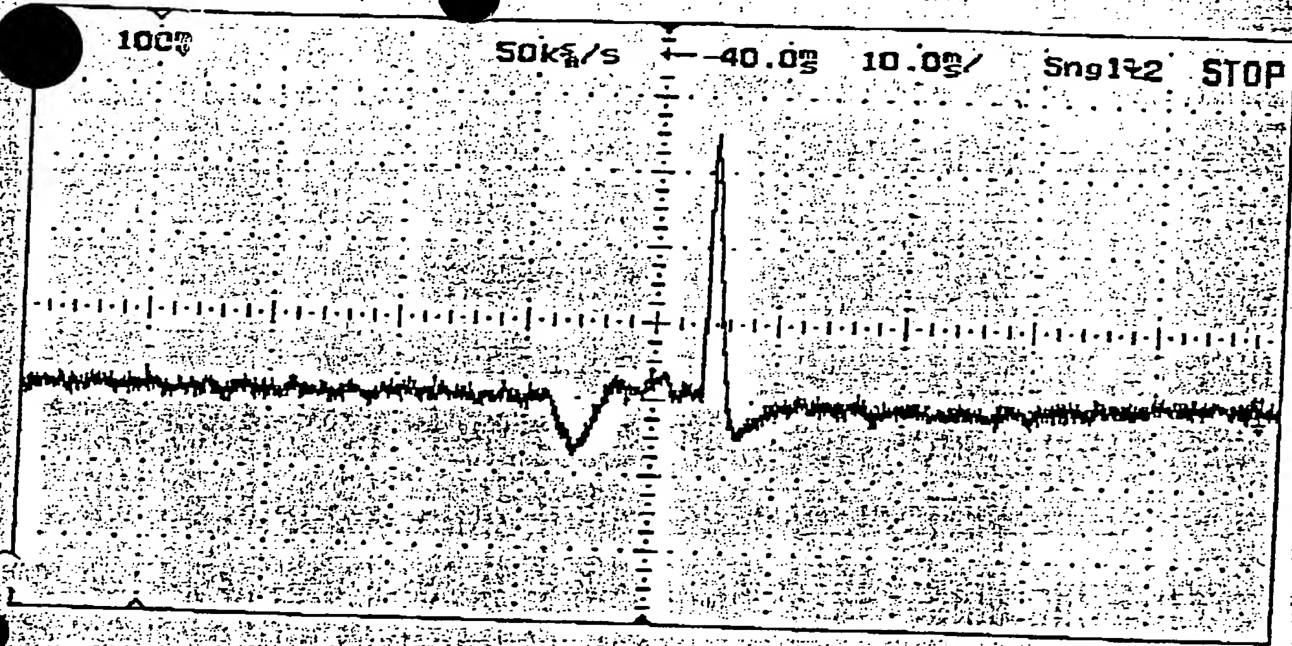

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Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

Trigger Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

Plo

100 / 1000 Hz

PLoL 6

7/10

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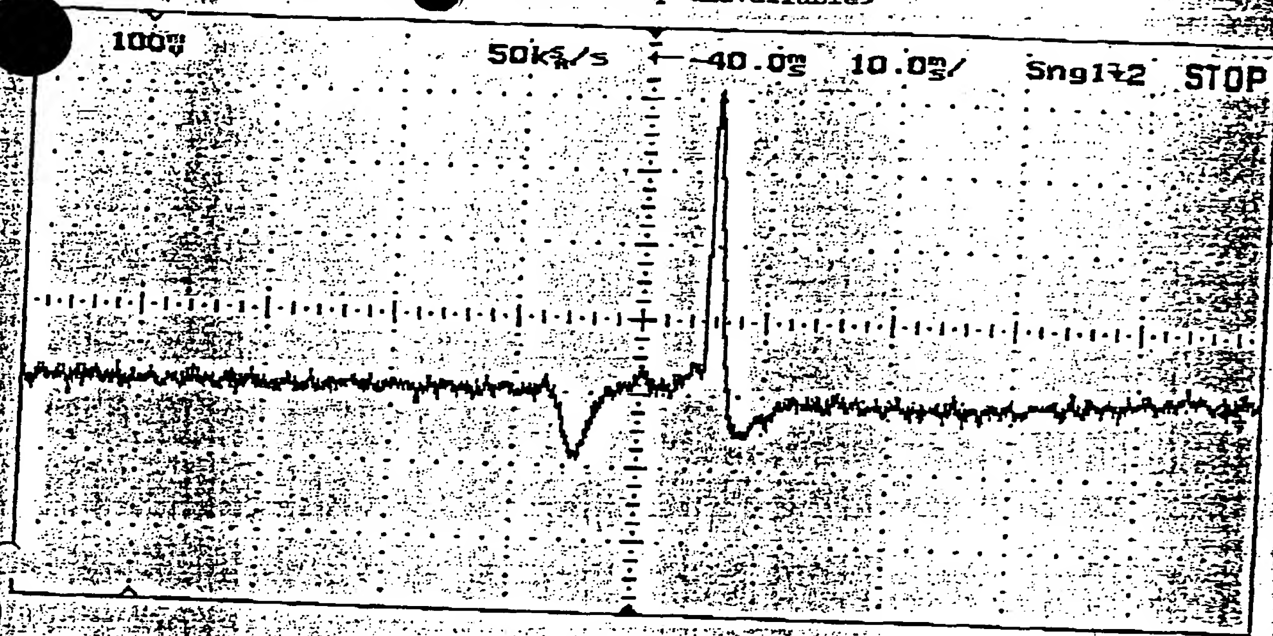

	State	Volts/Div	Position	Cplg	BW Lim	Inv	Probe	Input
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Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

Trigger Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

4 mm AC

100 / 1000 Hz

Plot 7

8/10

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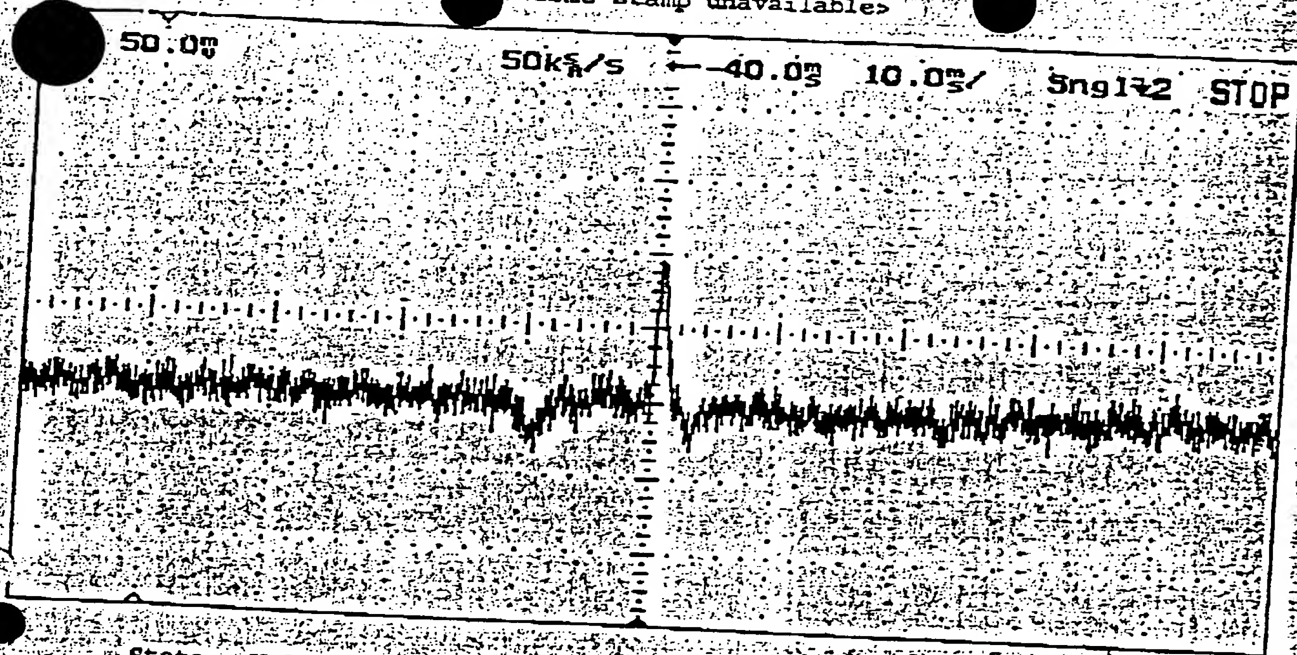

	State	Volts/Div	Position	Cplg	BW Lim	Inv	Probe	Input
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Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

Trigger Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

100 / 1000 Hz

12 mm AL

Plot 8

9110

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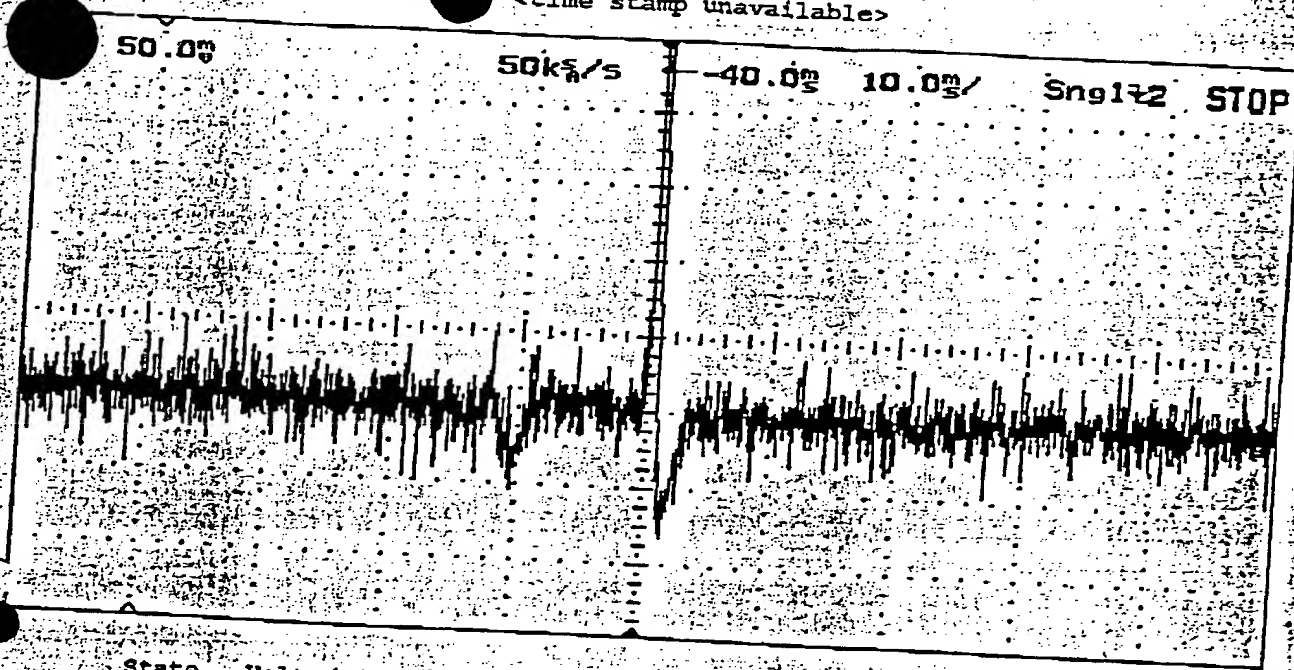

	State	Volts/Div	Position	Cplg	BW Lim	Inv	Probe	Input
Chan 1	On	50.00mV	-50.00mV	DC	Off	Off	10:1A	1M
Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	-----

	Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
Trigger	Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

Red/Reset on

4 mm AL

200/2000Hz

Plot 9

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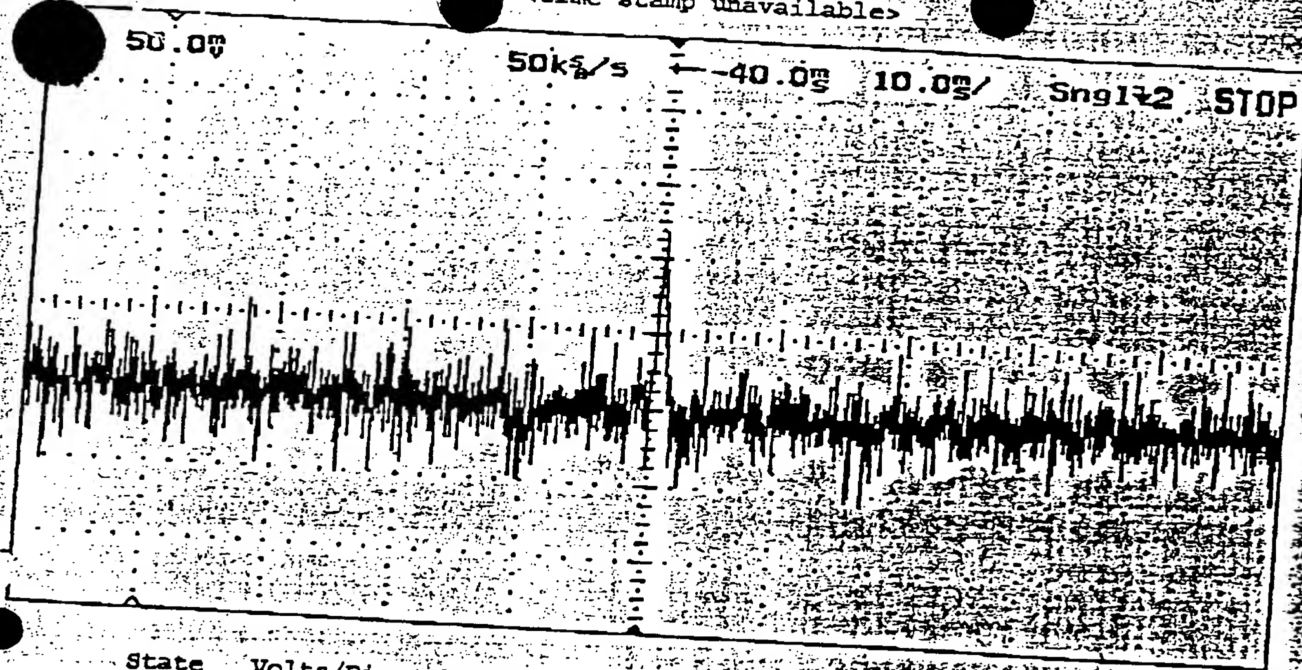

	State	Volts/Div	Position	Cplg	BW Lim	Inv	Probe	Input
Chan 1	On	50.00mV	-50.00mV	DC	Off	Off	10:1A	1M
Chan 2	Off	5.000 V	-156.3mV	DC	Off	Off	10:1A	1M
Ext	---	---	---	AC	---	---	1:1A	1M

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	10.00ms/	-40.00ms	Left	--------	

Trigger	Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
	Single	Ch 2	4.219 V	300.0ns	Neg	DC	Off	Off

Display Mode: Normal

100/1000 Hz

12 mm AL

Plot 10